Magnetic field vector retrieval with HMI

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Abstract. The Helioseismic and Magnetic Imager (HMI), on board the Solar Dynamics Observatory (SDO), will begin data acquisition in 2008. It will provide the first full disk, high temporal cadence observations of the full Stokes vector with a 0.5 arc sec pixel size. This will allow for a continuous monitoring of the Solar magnetic field vector. HMI data will advance our understanding of the small and large-scale magnetic field evolution, its relation to the solar and global dynamic processes, coronal field extrapolations, flux emergence, magnetic helicity and the nature of the polar magnetic fields. We summarize HMI's expected operation modes, focusing on the polarization cross-talk induced by the solar oscillations and how this affects the magnetic field vector determinations.

1. HMI polarization modulation

The HMI camera will measure the full Stokes vector at 5 wavelength positions along the Fe I 6173 Å line (Graham et al. 2002). The CCD has 4024×4024 pixels (0.5"/pixel). Our goal is to record the full Stokes vector for the whole solar disk with a cadence of 80-120 seconds. At each wavelength position two consecutive linear combinations of the solar Stokes vector are measured with a time delay of 4 seconds:

$$\mathbf{O}_{n \times 1} = \mathcal{M}_{n \times 4} \mathbf{I}_{\text{solar}} \tag{1}$$

Three different modulation matrices are under consideration: Mod A, Mod B and Mod C. The total time needed to scan the line in the four polarization states across five wavelength positions is $20n$ seconds (n is the number of rows in the modulation matrix in Eq. 2-4) : 80s for mod A-B and 120 s for C.

$$\mathcal{M}_A = \begin{pmatrix} 1.000 & 0.810 & 0.000 & 0.588 \\ 1.000 & -0.810 & 0.000 & 0.588 \\ 1.000 & 0.000 & 0.810 & -0.588 \\ 1.000 & 0.000 & -0.810 & -0.588 \end{pmatrix} \tag{2}$$
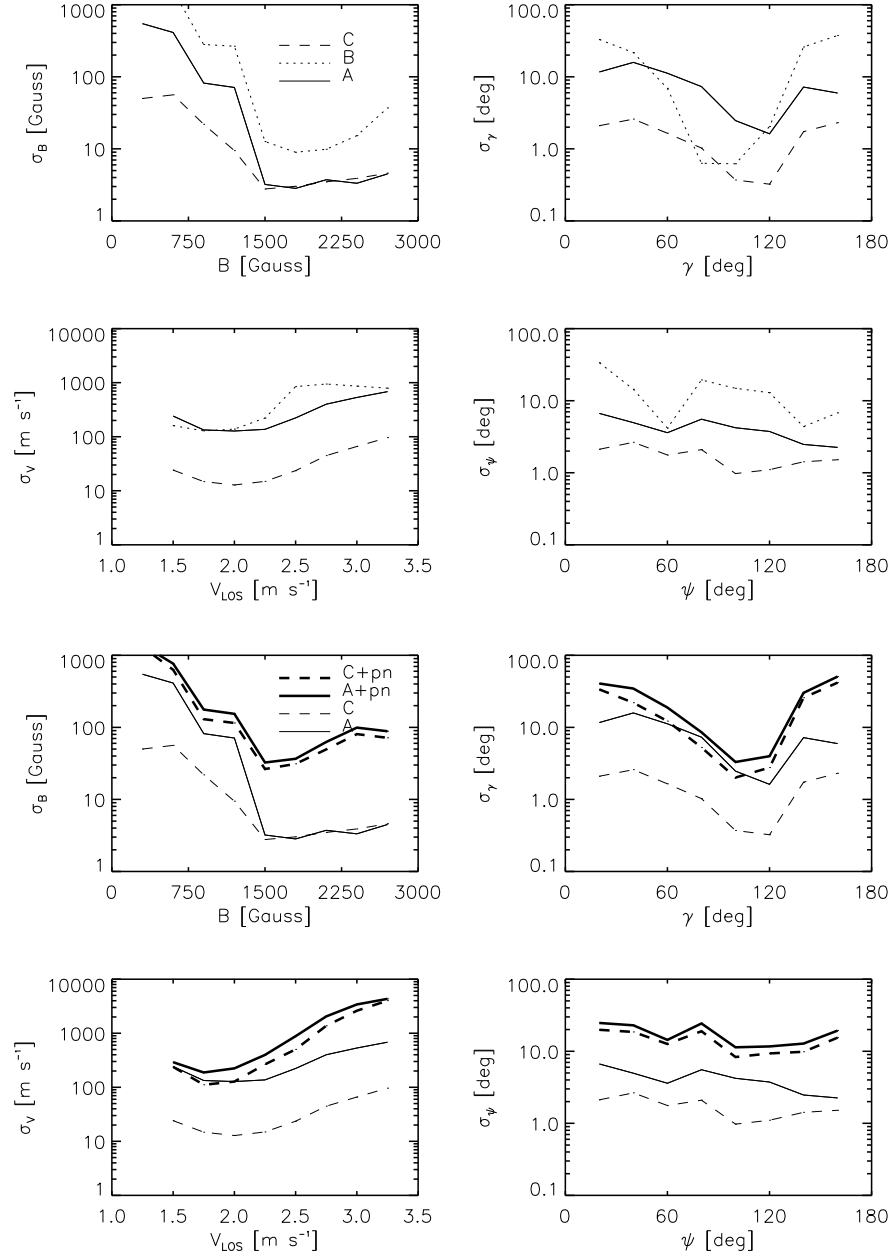
Figure 1. *Top 4 panels*: errors in the determination of magnetic field strength (upper left panel), field inclination (upper right), field azimuth (bottom right) and line of sight velocity (bottom left) as a consequence of the solar p-modes using three different modulation schemes: A (solid; Eq. 2), B (dotted; Eq. 3) and C (dashed; Eq. 4). *Bottom 4 panels*: Same as above but using only mod A and mod C. Thin lines correspond to results shown in upper four panel where only p-modes where considered. Thick lines represent the errors with p-modes and photon noise.

$$\mathcal{M}_B = \begin{pmatrix} 1.000 & 0.810 & 0.000 & 0.588 \\ 1.000 & 0.000 & 0.810 & -0.588 \\ 1.000 & -0.810 & 0.000 & 0.588 \\ 1.000 & 0.000 & -0.810 & -0.588 \end{pmatrix} \tag{3}$$

$$\mathcal{M}_C = \begin{pmatrix} 1 & 1 & 0 & 0 \\ 1 & -1 & 0 & 0 \\ 1 & 0 & 1 & 0 \\ 1 & 0 & -1 & 0 \\ 1 & 0 & 0 & 1 \\ 1 & 0 & 0 & -1 \end{pmatrix} \tag{4}$$

When the linear system is solved in order to obtain the solar Stokes vector, observations done at different times are mixed together. This introduces errors in the observed Stokes vector:

$$\mathbf{I}_{\text{obs}} = \mathcal{M}_{4 \times n}^{-1} \mathbf{O}_{n \times 1} \neq \mathbf{I}_{\text{solar}} \tag{5}$$

For example, at $t = 0$ modulation schemes measures $I + 0.81Q + 0.59V$ and at $t = 4$ seconds it measures: $I - 0.81Q + 0.59V$. Therefore we can obtain stokes Q by combining observations done 4 seconds apart. Note that to build Stokes V four different observations (obtained at different times) are mixed.

2. Effect of the Solar P-modes

To study the errors introduced in the determination of the solar magnetic field vector as a consequence of the solar p-modes, we take them into account when computing $\mathbf{I}_{\text{obs}}$. The different profiles (that enter into Eq. 5) are shifted in quantities that correspond to the velocity changes associated with the solar p-modes. They are then inverted using a Stokes inversion algorithm (Skumanich & Lites 1987) that retrieves: the magnetic field vector, line of sight velocities and a filling factor (fractional area of the pixel covered by the magnetic atmosphere). Results from the inversion are displayed in Fig. 1 (top panels).

3. Photon noise

The noise level for a single observation using HMI will be about 0.2×10^{-3} in units of the continuum intensity. This number considers a light level of the quiet Sun at disk center. For off-limb observations and/or darker regions (sunspots) the noise level will be different. A realistic simulation has been performed taking into account the solar p-modes effect and photon noise simultaneously. In this case we restrict ourselves to consider only modulation schemes A and C. Results are presented in Fig. 1 (bottom panels).

4. Temporal averages

Due to the oscillatory nature of the solar p-modes, its effect on the observed profiles can be reduced if we use time averaged profiles. By doing so we can

improve the accuracy in the determination of the magnetic field vector. Note that time averaging will also reduce the effect of the photon noise.

We have carried out several simulations using different averaging times. Fig. 2 displays the errors in the determination of the magnetic field vector as a function of the time used in the average. This was done both for Mod A and C. We distinguish between different solar regions by taking averages of pixels with different filling factors.
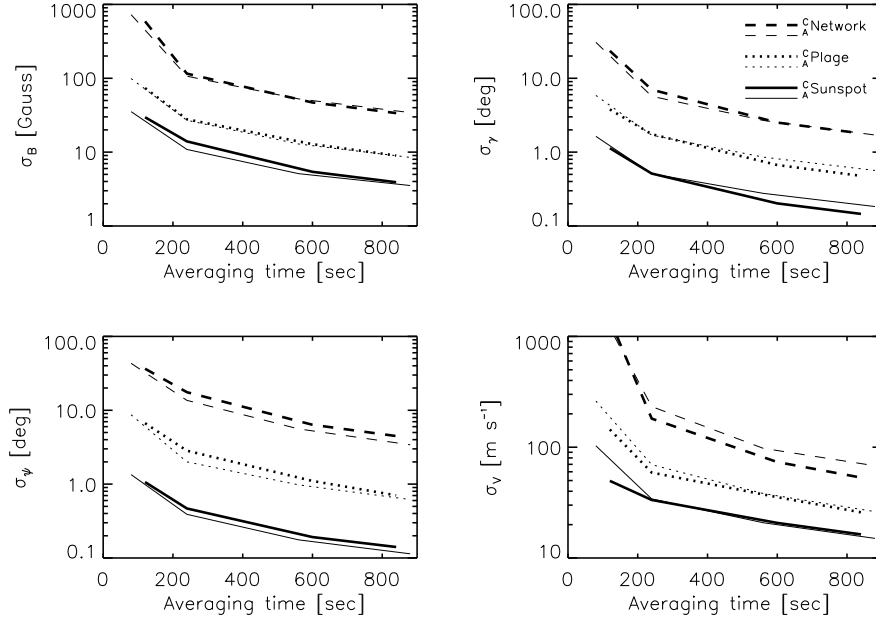

Figure 2.   Retrieved errors as a function of the averaging time. Thin and thick lines correspond to Mod A and C respectively. Line styles indicate different solar regions: dashed (network), dotted (plages) and solid (sunspots).

5.   Conclusions

HMI will provide full disk observations of the magnetic field vector with a cadence of 80-120 s and a spatial resolution of 0.5 arc sec. We have considered the main sources of error in the data and estimate how this will affect the reliability of the inferred vector. Accuracy can be improved by using time averaged observations. For a 10 minutes average, the magnetic field in sunspots and plages can be known with a precision better than 10 Gauss and 1° in inclination and azimuth.

References

Skumanich & Lites 1987, ApJ, 322, 473

Graham, J.D., López Ariste, A., Socas-Navarro, H. & Tomczyk, S.: 2002, *Solar Phys*, 208, 211